

# Thinning Satellite Data Using Wavelets for Weather Forecasting

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# Motivation

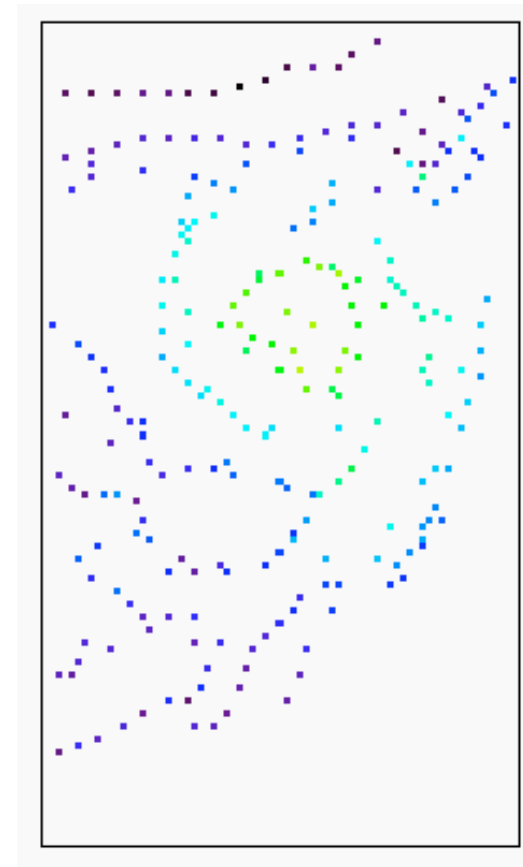
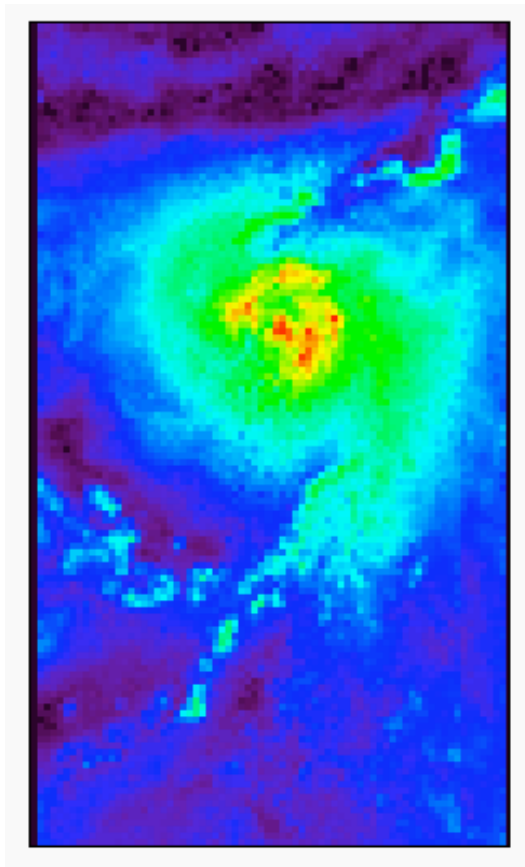
- **Operational weather prediction centers use only a fraction of observations made by satellite**
- **Wavelet analysis should be able to provide an adaptable selection method**



# Goals

- 1. Improving the selection and impact of the vast, information-rich and valuable satellite observations of the Earth system**
- 2. Combining mature technologies (atmospheric data assimilation and wavelet analysis) for a novel and practical use**
- 3. Raising the technology readiness level (TRL) of this technique to a working prototype in a realistic setting.**

# SeaWinds wind speeds/selected



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# Impact tests

- We test our thinning technique by data assimilation in atmospheric models with a 2d- and 3d-variational methods
- The baseline case assimilates all available data (ALL)
- Experiments assimilating thinned subsets of the data by regular decimation and wavelet-based selection are evaluated for information content



# Results

- **Wavelet-based selection is roughly equivalent to regular decimation to every 8th or 10th datum**
- **A new noise thresholding approach was developed in response to the small signal-to-noise ratio for small scales**
- **Impact to date on NWP systems is inadequate**

# SeaWinds on QuikSCAT



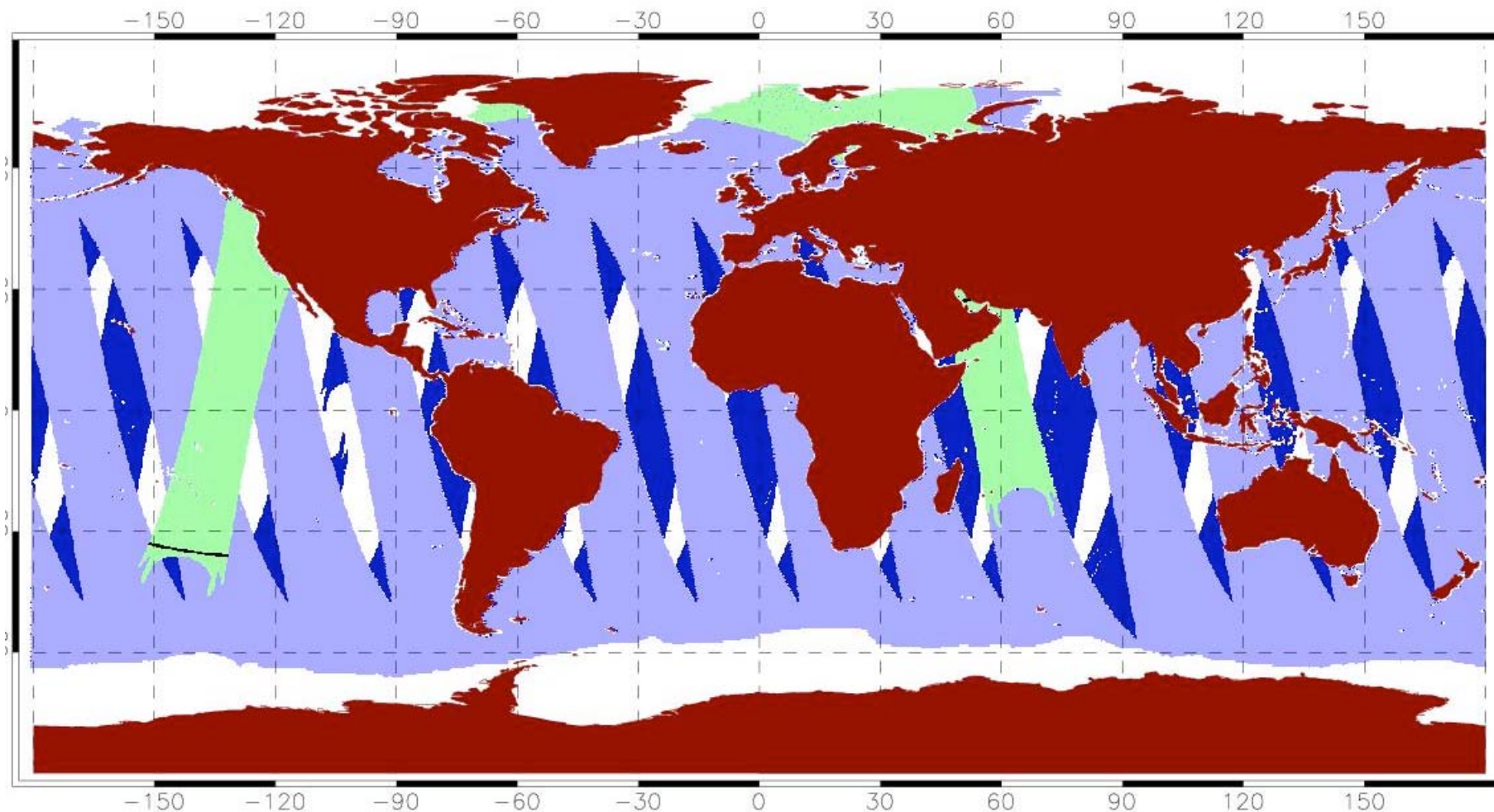
## SeaWinds Instrument



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# QuikSCAT NRT passes



- November 1, 2000
- Dark blue: descending, Light blue: ascending, Green: one pass

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# Wavelet selection



- **Continuous Wavelet Transform (CWT) uses the conventional Canny analyzing wavelet**
  - **The Canny CWT simultaneously detects, localizes, and characterizes edges in the observations**
- **The CWT first is applied with a wavelet oriented across the satellite track and then along the satellite track.**
  - **The two sets of coefficients yield wavelet amplitudes and phases for each pixel at each scale**
- **CWT provides spatial information on six dyadic scales (25, 50, 100, 200, 400, 800 km)**

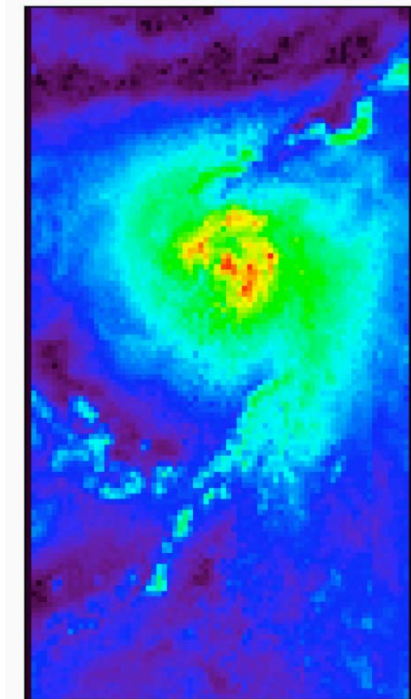


# Feature identification

- **Identify the wavelet transform modulus maxima (WTMM) at each scale**
- **Create wavelet maxima chains from the WTMM by comparing nearest neighbors**
- **Perform wavelet noise reduction to eliminate extraneous WTMM chains**
- **Connect WTMM chains through scales to create wavelet ridge (skeleton)**

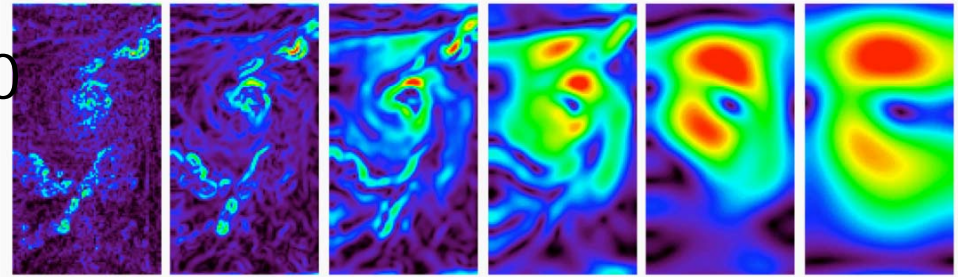
# CWT for Typhoon Meranti

Meranti 2004/08/07 1800

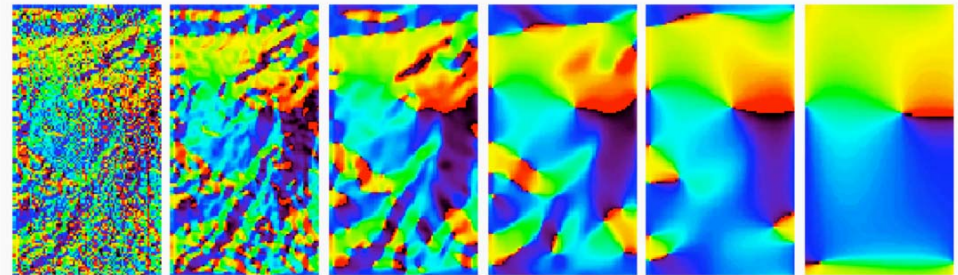


0 10 20 30  
Wind Speed (m/s)

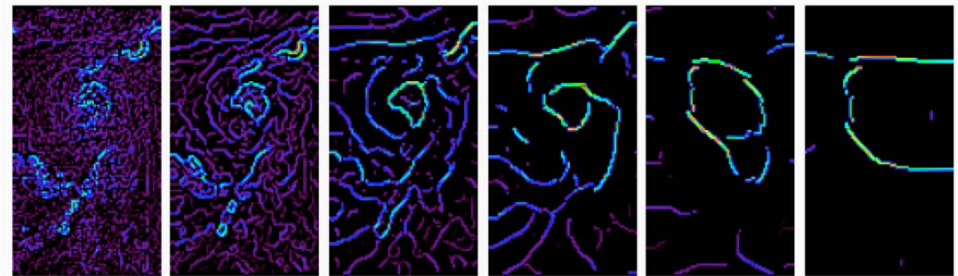
a)



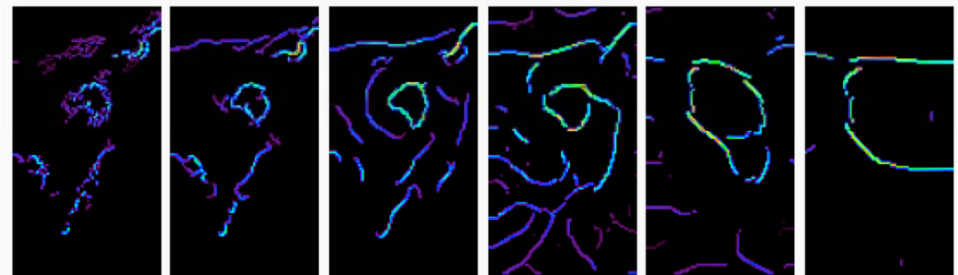
b)



c)



d)



km 25 50 100 200 400 800

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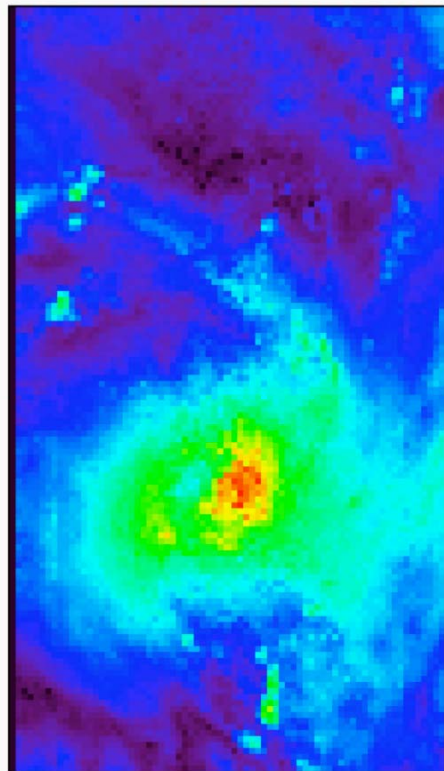
# Bayesian partitioning of signal and noise

- To accomplish noise removal on all scales without specifying thresholds, we developed a Bayesian approach
- We model the squared modulus as a two-component Gamma distribution
- We calculate posterior probability that each wavelet coefficient is significant
- Significant coefficients are retained

# Noise thresholding

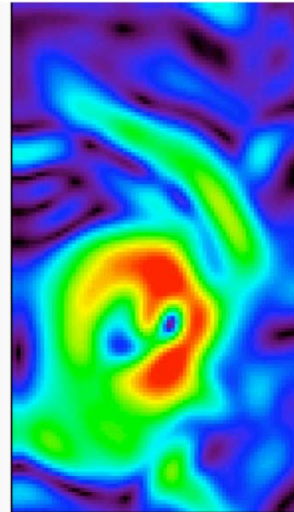


Meranti 2004/08/07 0600

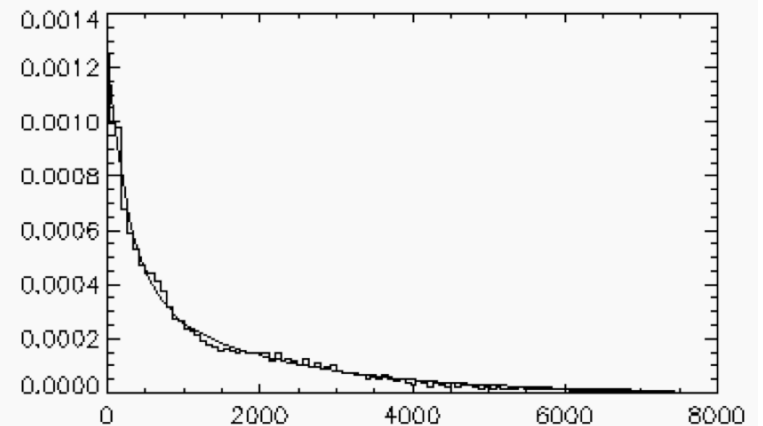
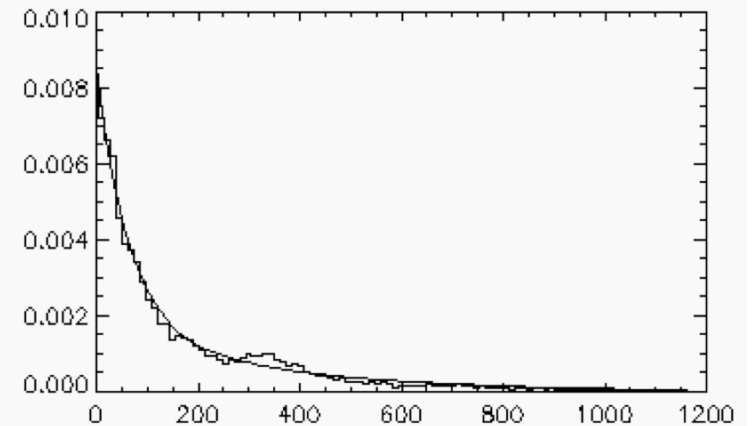
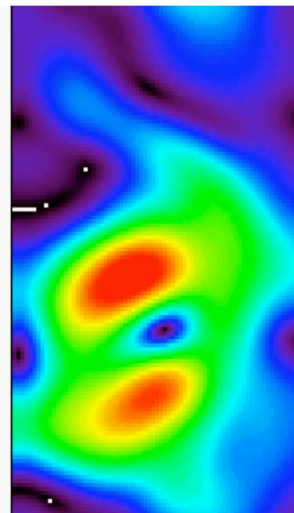
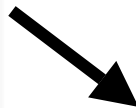


0 30 m/s

Scale  $2^3$



Scale  $2^4$



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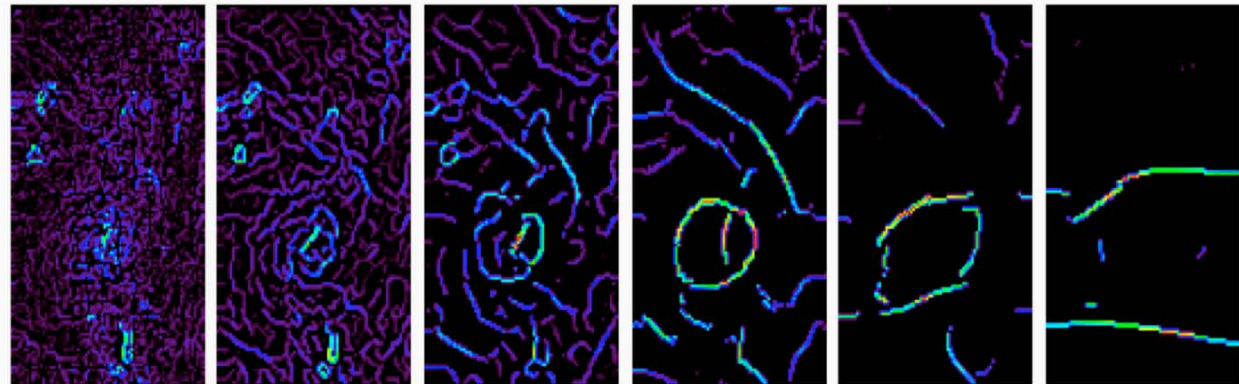
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# Noise reduction

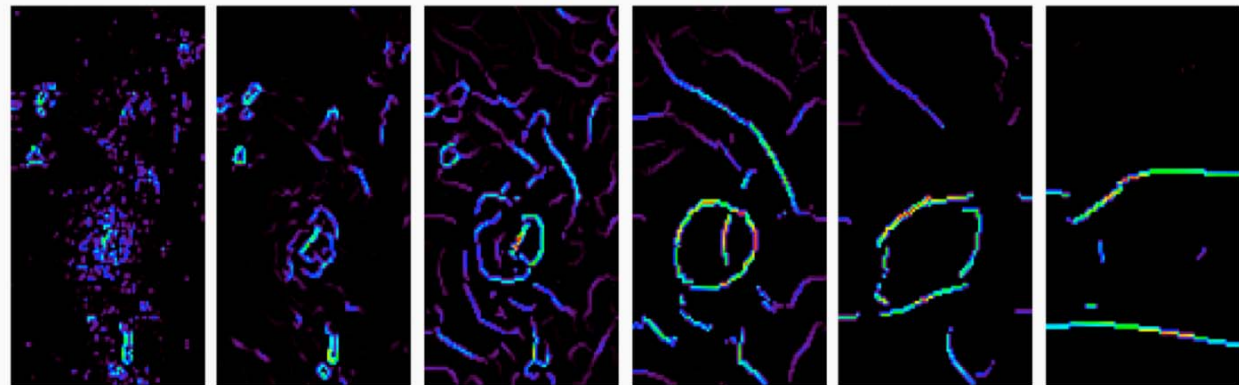


Meranti 2004/08/07 0600

Before wavelet  
noise reduction



After wavelet  
noise reduction



Dyadic Scale

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0

1

2

3

4

5

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# Signal skeleton construction

- **Compare WTMM chains for each scale with those from the next largest scale**
  - **Consider only remaining chains after noise thresholding**
- **Retain only those WTMMs that track down from the larger scale**
  - **To track down, the WTMM must be located to within a scale size neighborhood of the position of the larger scale WTMM**



# Point selection

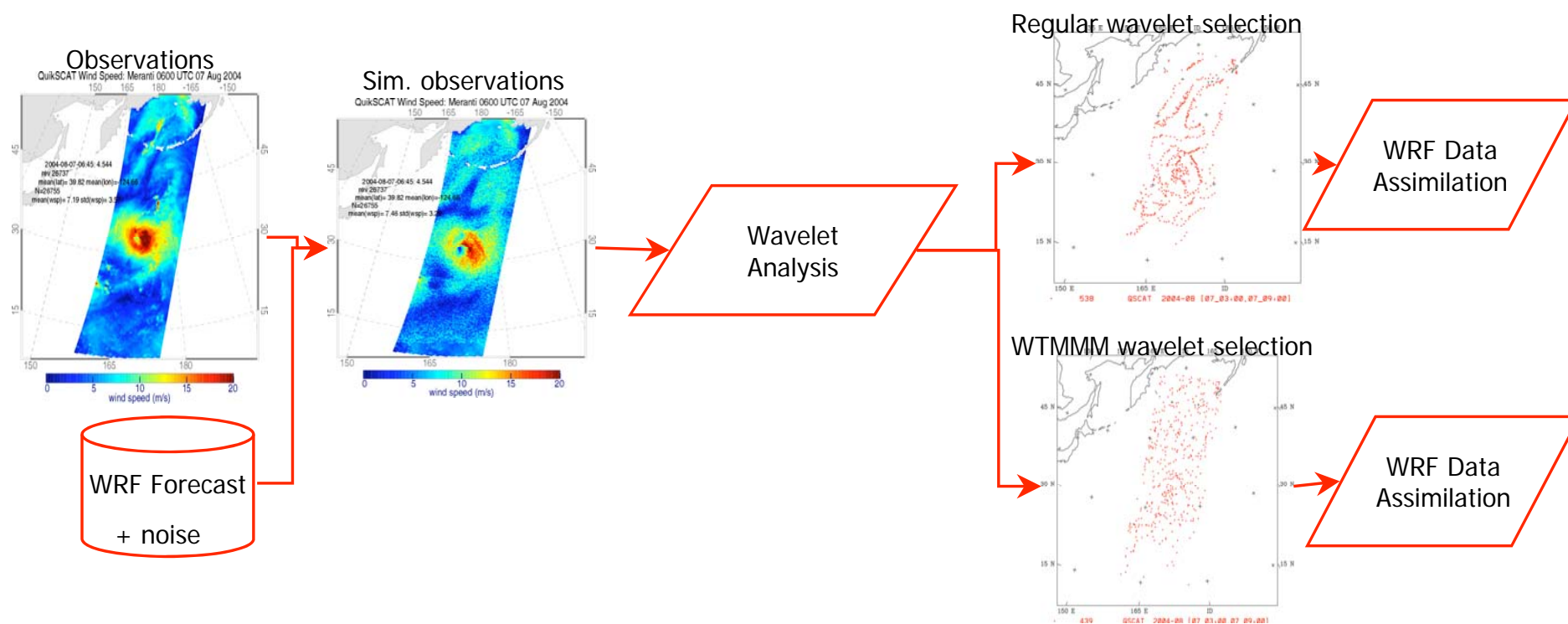
- **Regular wavelet selection**
  - **Select data points along wavelet ridge lines in the wavelet skeleton with spacing matched to each scale size**
- **WTMM maxima selection**
  - **Select points where the amplitudes of the wavelet coefficients are locally maximum along the wavelet ridge lines**



# Evaluation of thinned and decimated SWS data

- **Simulation tests comparing atmospheric analyses using wavelet-selected and regularly decimated data**
- **Future tests should be based on forecast impacts using real data**
- **Case selection strategy that only considers satellite data within ~10 minutes of synoptic times**

# Experiment setup

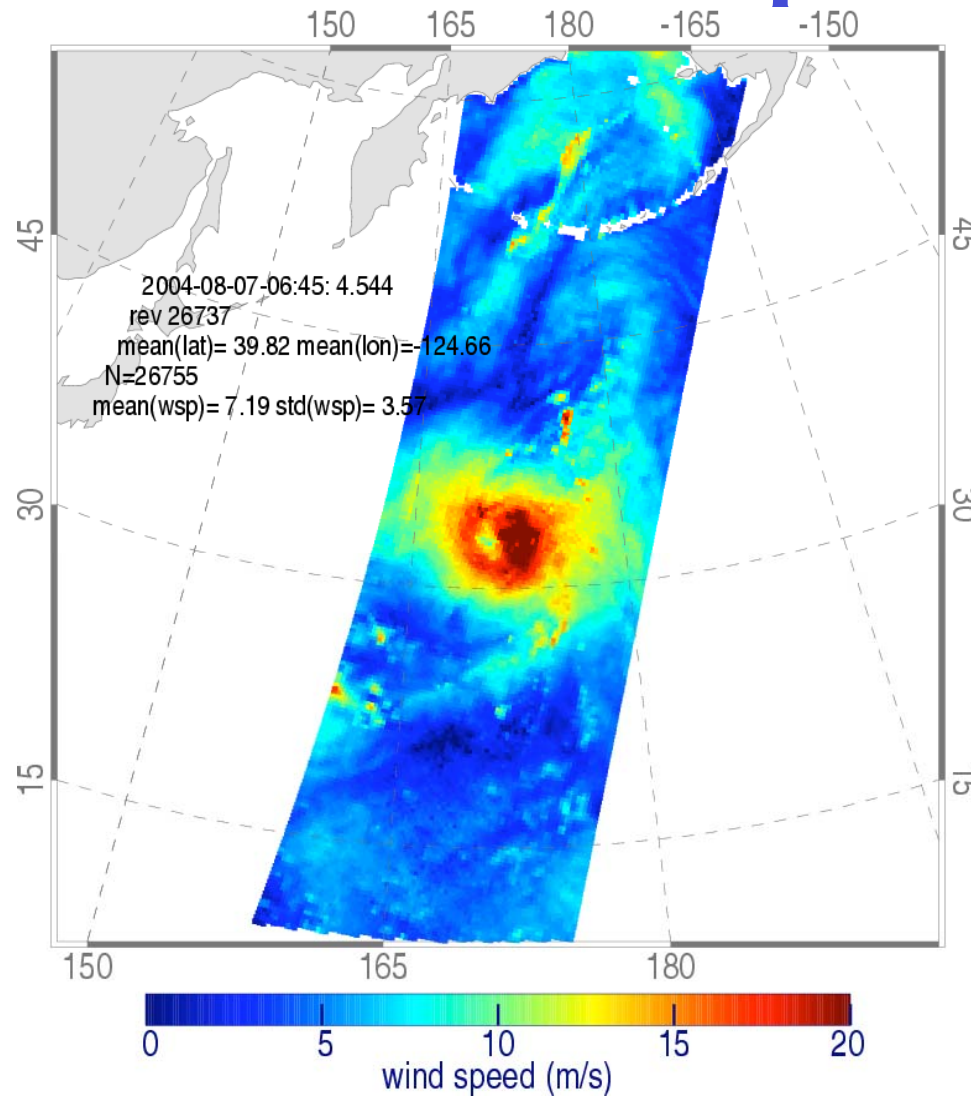




# Simulated observations

- **Weather Research and Forecasting (WRF) model forecast taken to be the “true” atmosphere**
  - **201 x 201 x 30 grid points**
  - **Horizontal spacing of 27 km**
  - **Model top at 50 hPa**

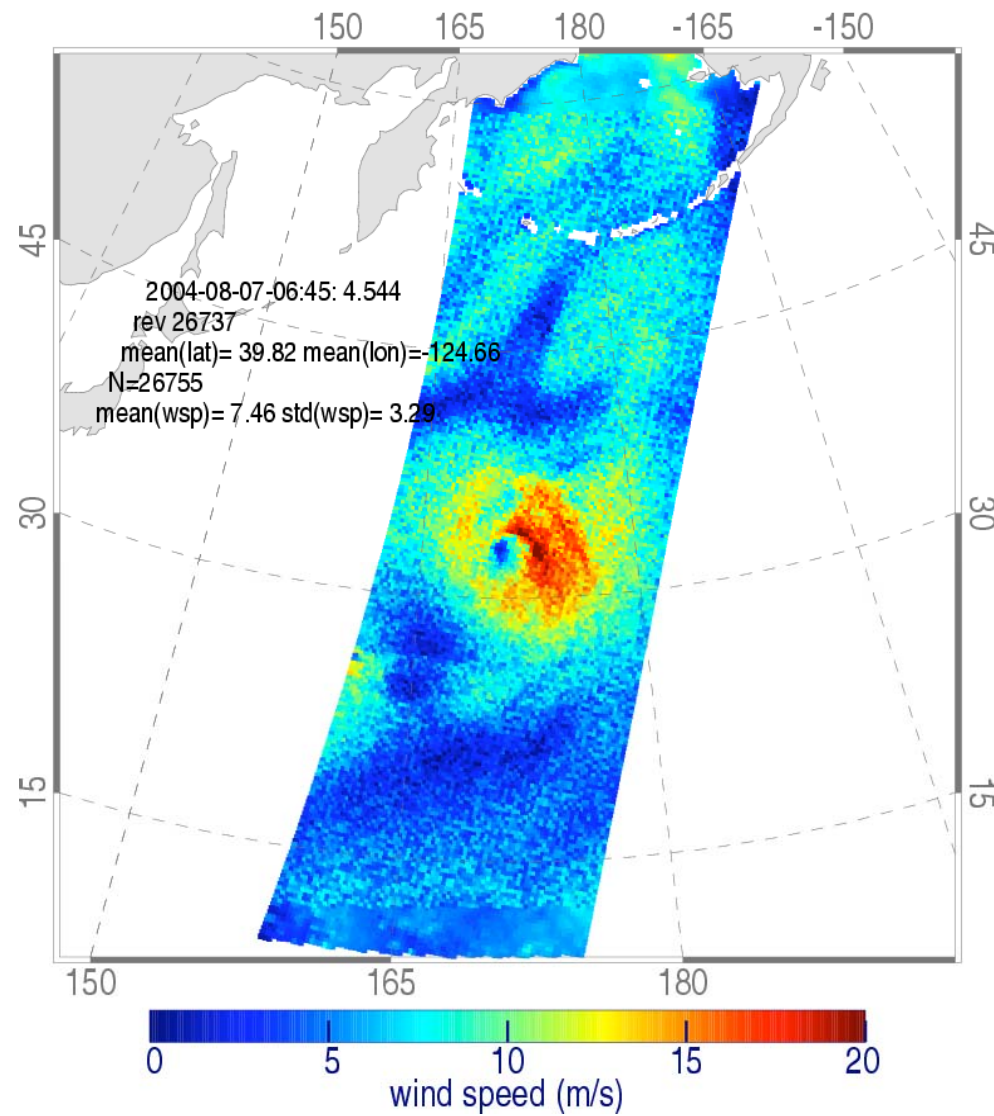
# QuikSCAT wind speeds



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# Simulated data



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# Cases

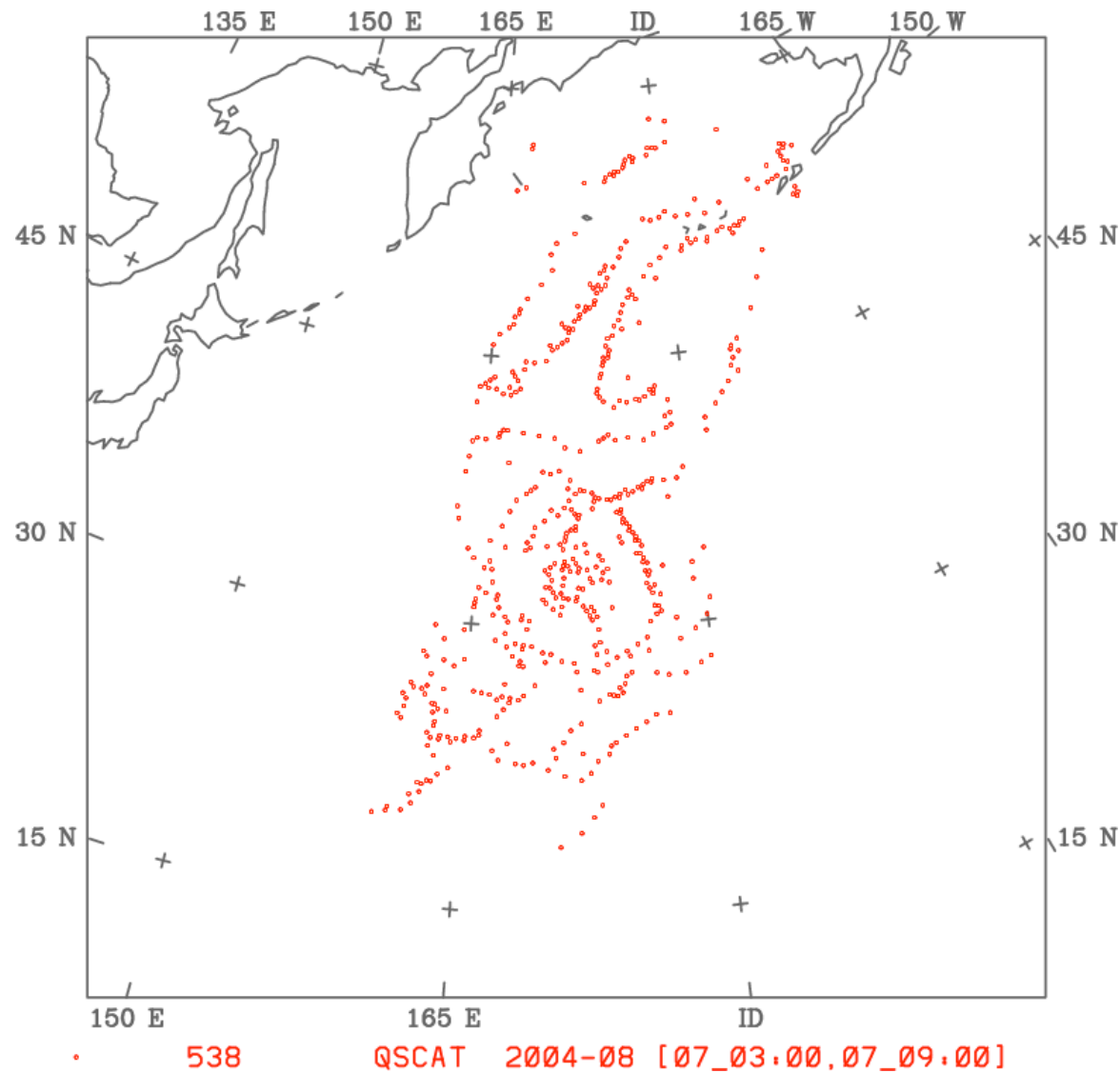
- **Pacific Typhoon Meranti (August 2004)**
- **An anticyclone in the South Indian Ocean (October 2004)**
- **Very light winds in the tropical Pacific (March 2005)**



# Treatments

- **ALL**
- **THIN2: every 2nd datum**
- **THIN4: every 4th datum**
- **THIN6: etc.**
- **THIN8 ...**
- **THIN10 ...**
- **WAVELET: along WTMM chains**
- **WAVELET4: WAVELET + THIN4 points**
- **WAVELET6: ... + THIN6 points**
- **WAVELET8: etc.**
- **WAVELET10 ...**
- **WTMMM: WTMM maxima selection**

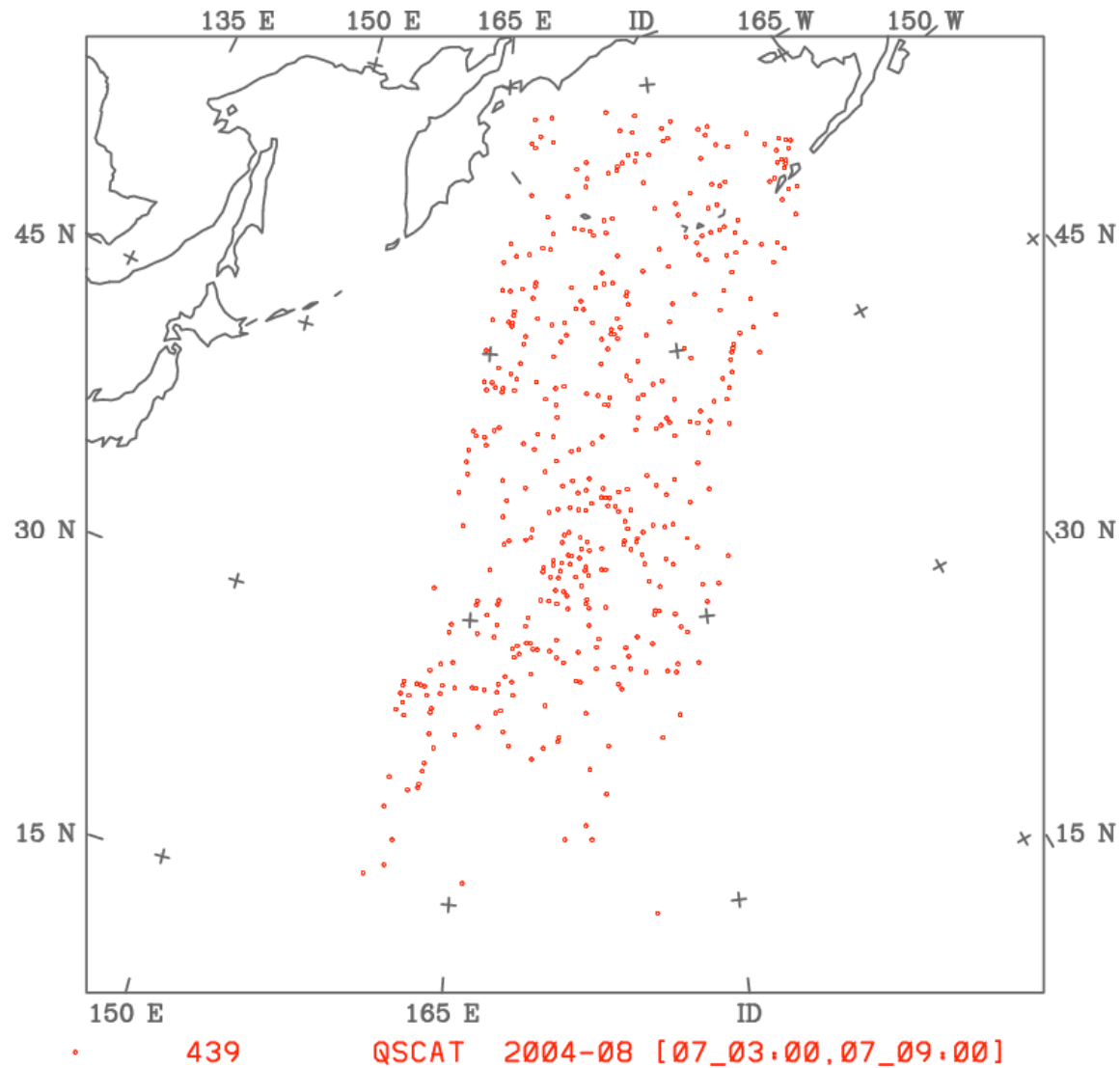
# Regular Wavelet Selection (WAVELET)



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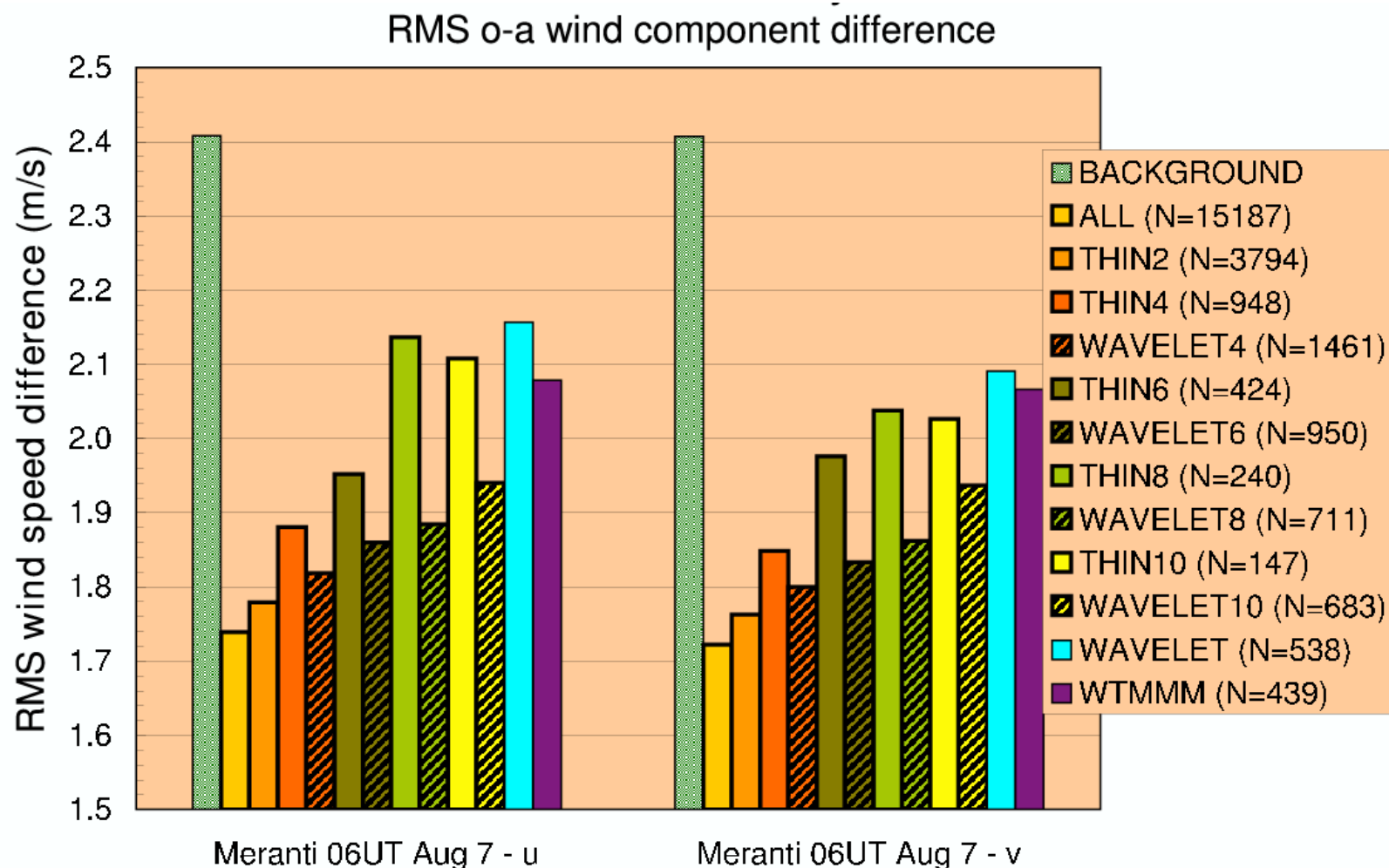
# WTMM Maxima Selection



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# Verification of data assimilation experiments





# Results

- **Using all of the data (ALL) produces the best analysis**
- **Accuracy of the THINx analyses generally degrade as more data are thinned**
- **Wavelet only selected data have poor accuracy**
- **Marginal improvements using wavelet selection plus very low density of decimated data**



# Future work

- **Use innovations (obs-background)**
- **Test other wavelet analysis functions**
- **Multi-wavelet analysis**
- **Real-data forecast experiments**
- **Migrate current prototype to operational system**
- **Application of CWT for cloud edge detection**



# Wavelet thinning

- The amplitudes of the wavelet coefficients from two passes of the CWT identify edges and gradients
- The CWT provides information on six spatial scales (25, 50, 100, 200, 400, 800 km)
- Features are identified at each spatial scale
- The final data selection is the union of all points selected at every scale

# Hurricane Isaac



Green: rain contaminated

Red square: best track location at time of satellite image

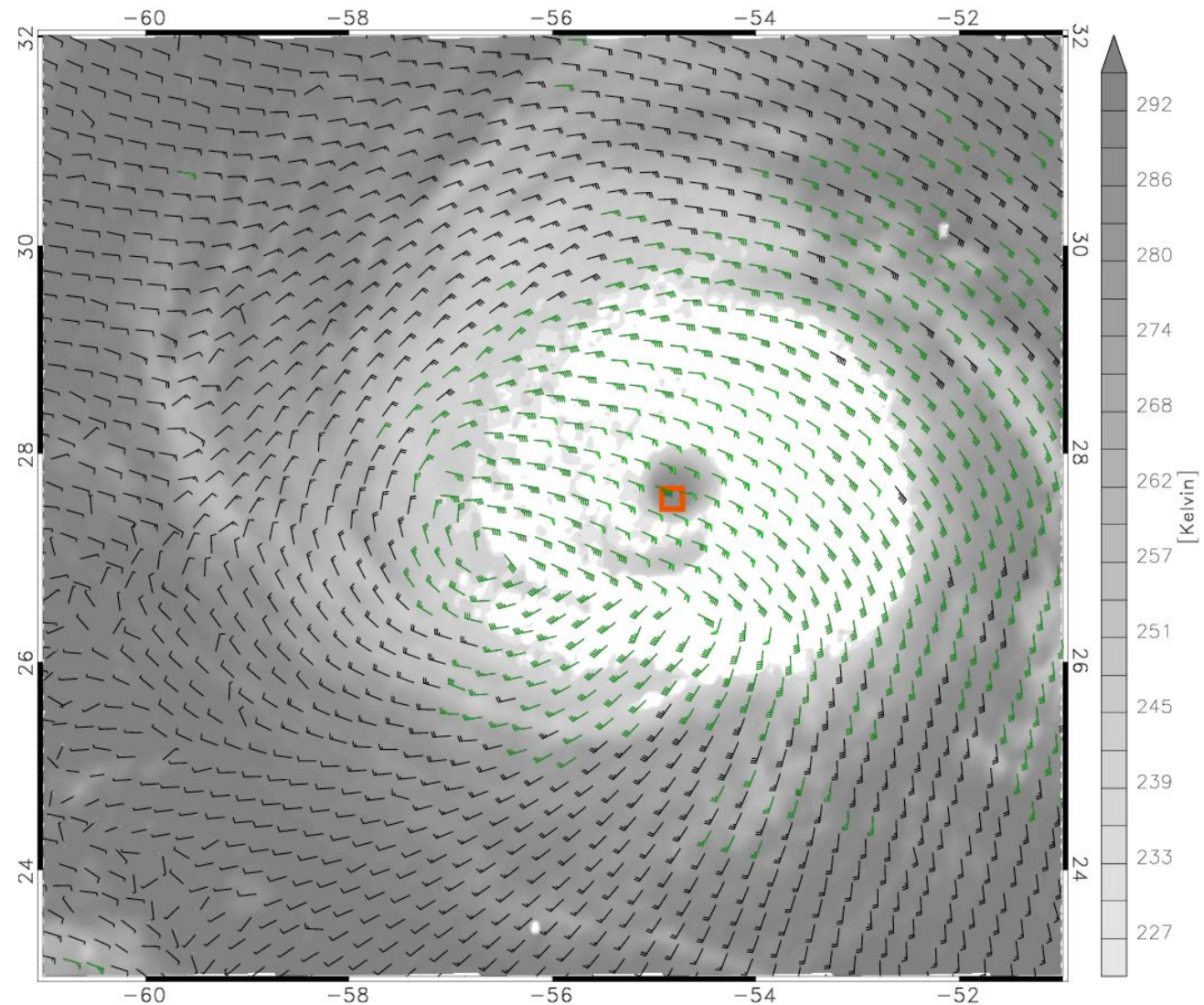
Central pressure: 948 hPa

Estimated maximum winds: 59 m/s (115 kt)

Ambiguity removal error

Rain flag too aggressive

Maximum scatterometer winds, 36.4 m/s (71 kt), only 60% of estimated maximum winds



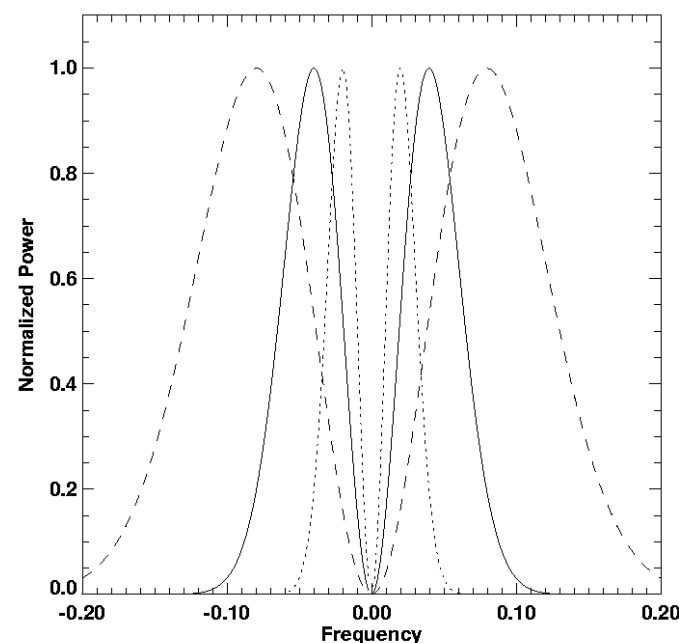
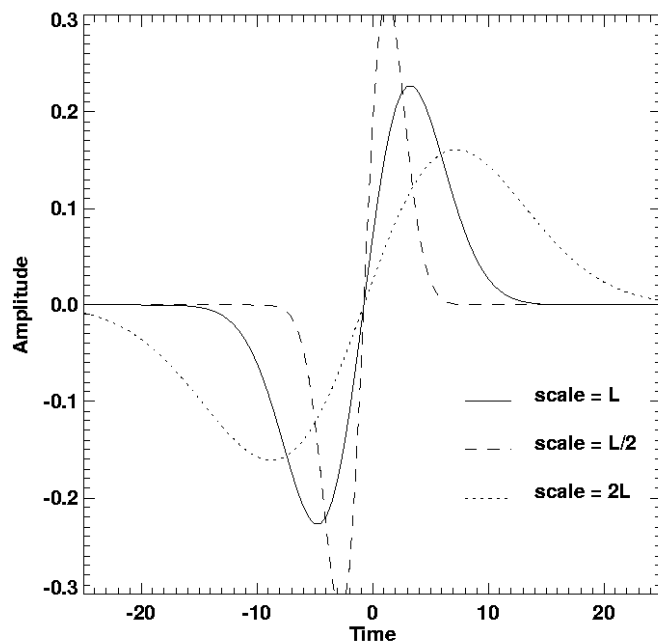
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# CWT advantages

- **Uses a set of nonorthogonal wavelet frames to provide a highly redundant representation**
- **Provides a wavelet coefficient at each analysis scale for each pixel in the image**
- **Allows a characterization of the local information content**
- **Redundancy improved the stability of the inverse transform in the presence of noise**

# Canny Wavelet



$$\psi_{Canny}(x) = \pi^{-1/4} x e^{-x^2/2}$$

- One vanishing moment:  $n=0$
- Edge Detector